TONE COLOR

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AT ordinary temperatures, waves of sound in air advance at the rate of 340 meters (1,120 feet) per second. By wave-time is meant the time of advance from a given position to the position of the preceding wave. It is recognized by the ear as the pitch of the tone. Wave-length, the distance between the crests of two consecutive waves, is the product of the velocity and the wave-time. The wave-length of audible sounds in air varies from one centimeter for the highest to twenty meters for the lowest note. Sounds whose wave-lengths are less than a centimeter are not heard by human ears. Sounds with waves longer than twenty meters are heard as a series of beats, but not as a continuous note. The wave-time of middle C on the piano is 39 ten-thousandths of a second.

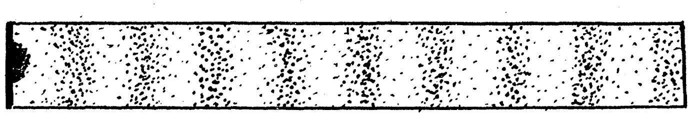

FIG. 1. DIAGRAM OF A SOUND WAVE IN AIR. Wave-length, one centimeter. Wave-time, 0.3 ten-thousandths of a second.

The loudness of the sound depends upon the amount of energy contained in its wave. For waves of a given pitch and quality this increases with the amplitude, that is, with the extent of motion of the air-particles during the passage of the wave.

Sound waves are impressed as up-and-down indentations on a graphophone cylinder or an Edison disk, and as side-to-side wavy grooves on the ordinary disk of a gramophone. They are conveniently and clearly represented on paper as up-and-down waves proceeding from left to right, in which the down part of the wave indicates compression and the up part expansion of the air.

The simplest form of a wave is the sine curve (Figure 2). Its tone is smooth and clear, like the tone of a tuning fork or a flute. Many instrumental waves are compound sine curves,

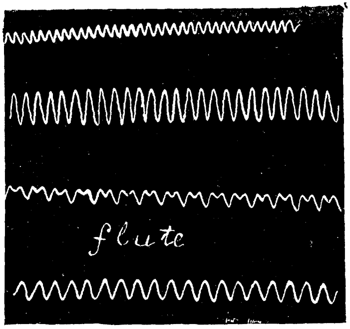

FIG. 2. FLUTE WAVES, ENLARGED FROM A GRAPHOPHONE RECORD. Magnified vertically 2,000 times. Each line is made by a single note.

FIG. 3. VIOLIN WAVES, × 2,000.

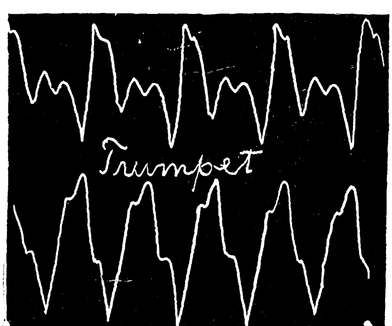

FIG. 4. TRUMPET WAVES, × 2,000.

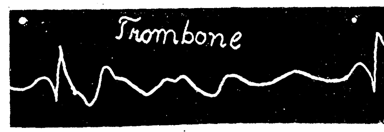

FIG. 5. WAVE FROM A LOW NOTE OF A TROMBONE. The whole curve between the sharp upper points is a single wave. × 2,000.

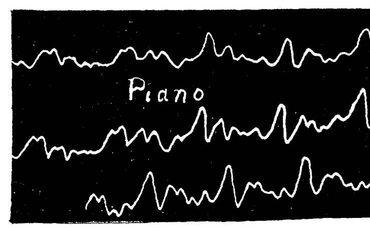

FIG. 6. PIANO WAVES, × 2,000. The first two lines are two successive tracings over the same wave-record, given to show the degree of accuracy of the enlarging machine.

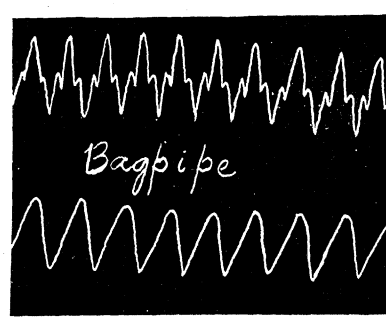

FIG. 7. BAGPIPE WAVES. The upper line, like the third line in figure two, shows a compound note. × 2,000.

consisting of a fundamental long sine wave, to which are added shorter sine waves whose lengths are submultiples of the first. The form of these compound waves gives to each instrument its characteristic timbre or quality, by which, for example, the note sounded by a violin is distinguished from a note of the same pitch and loudness made by a cornet.

Notes sung by a human voice differ radically from such instrumental notes, in that their smaller superposed waves have no fixed ratio to the fundamental wave. In the voice the fundamental wave, which decides the pitch of the vocal note, is produced by a rapid succession of puffs of air forced from the lungs through the slit between the closed and stretched vocal cords.

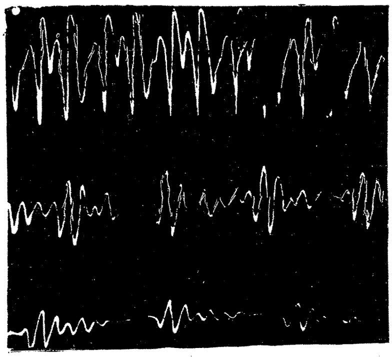

FIG. 8. THE SOUND OF *a* IN HAT, × 2,000. The upper line shows 5 or 6 wave groups, of moderate pitch; the second is a low note; the third very low, with long wave groups.

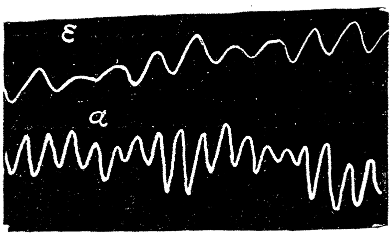

FIG. 9. THE LOWER LINE SHOWS A VERY LOW NOTE OF *a* IN HAVE: THE UPPER A LOW NOTE OF *a* IN MADE. × 2,000.

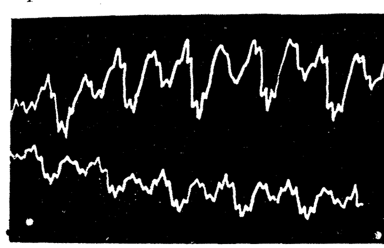

FIG. 10. WAVES OF *ee* IN DEEP. × 1,200.

Tightening the cords increases the rate of the puffs and therefore raises the pitch. Following each puff the air in the throat, nose and mouth is thrown into more rapid oscillation, like the air in an organ pipe; and these smaller resonance waves, which are added to the pitch wave, are the source of the different vocal qualities. Vowel quality, for example, depends on the lengths of the resonance waves present. The short sound of *a*, as in "hat," has a resonance wave-time of 14 ten-thousandths of a second. The long sound of *a*, as in "made," has 24 ten-thousandths. The sound of *ee* in "deep" has two resonance waves; one whose wave-time is 1½, the other 20 or more, ten-thousandths of a second.

The term tone color is sometimes used to express timbre, or tone quality of any kind. I propose to restrict its use here to that kind of tone quality which is independent of the form, amplitude, time, or length of the wave.

The tone colors of the notes of the diatonic scale have been variously described. One set of descriptive words is so selected

as to begin with the same letters as the names of the notes to which the words apply. Another set is similarly related to the letters on the staff in the scale of C.

do′	defiant	C′	Clearness
ti	trying	B	Brightness
la	lurid	A	Adversity
so	strong	G	Gladness
fa	fateful	F	Faith
mi	mild	E	Ease
re	rousing	D	Desire
do	dauntless	C	Constancy

These diatonic colors were personified by a young lady teacher, for the benefit of her younger pupils, in the story of

THE DO FAMILY

When they receive visitors at their home by the C the members of this family always sit in a row in their parlor. First comes Father Do, next to him a husky boy Re, and his little sister Mi. Beside Mi sits her melancholy brother Fa, and next to him the big brother So. Grandma La comes next and helps to look after Baby Ti, who always keeps close to Mother Do.

The diatonic colors whose nature is suggested by these various expressions are unchanged by a change of the key. It follows that they are due to the relation that each note bears to the key note. What this relation is will now be shown.

A stretched string or a column of air vibrating as a whole gives out its lowest or fundamental tone. If it vibrates as two separate halves the note is an octave higher and the wave-time is one half as great. If it vibrates in three equal lengths the note is *so* in the next higher octave, and the wave-time is one third. Proceeding in this way we obtain a series of notes from which a selection is made to form a "natural scale." The notes of the diatonic natural scale have the wave-times and wave-lengths, relative to the lowest note, given in the first line of fractions below.

do	re	mi	fa	so	la	ti	do
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$
	$\frac{8}{9}$	$\frac{9}{10}$	$\frac{15}{16}$	$\frac{8}{9}$	$\frac{9}{10}$	$\frac{8}{9}$	$\frac{15}{16}$

The second line of fractions gives the ratio of the wave-time of each note to the one before it. From this it appears that there are three kinds of intervals between the notes. Two of them, $\frac{8}{9}$ and $\frac{9}{10}$, are nearly equal; the third, $\frac{15}{16}$, is about half as great as either of the others.

If a piano or organ were tuned to the natural diatonic scale all the music played on it would have to be played in the key of C, or the intervals would not fit the music. A change of key would not be possible.

To overcome this difficulty Bach, 200 years ago, devised the Tempered Chromatic scale, in which each octave is divided into twelve equal intervals, or twelve tempered chromatic *tones*.[1] The wave-times of the several notes of this scale are found from the time of the key note by dividing repeatedly by the twelfth root of 2 (=1.0495).

The following table shows the relation of these notes to each other, and also to the notes of the natural diatonic scale. It will be seen that *do*, *re*, *fa* and *so* are practically identical in the two scales, and that the difference of wave-time for *mi*, *la* and *ti* is in each case less than one per cent.

Diatonic Natural Scale			Tempered Chromatic Scale		
Note	Ratio to Keynote		Tones Above Key	Ratio to Key	Approx. Simple Fraction
do′	1/2	.5	12	.5	1/2
ti	8/15	.533	11	.530	9/17
—			10	.561	9/16
la	3/5	.600	9	.595	3/5
—			8	.630	5/8
so	2/3	.667	7	.667	2/3
—			6	.707	12/17
fa	3/4	.750	5	.749	3/4
mi	4/5	.800	4	.794	4/5
—			3	.841	5/6
re	8/9	.889	2	.891	8/9
—			1	.944	17/18
do	1	1.000	0	1.000	1

The strongest note, *so*, of the diatonic scale bears the simplest time-ratio, $2/3$, to the key note. The note next in strength, *fa*, has the ratio, $3/4$, next in simplicity. The most complex ratio, $8/15$, belongs to the note *ti* whose tone color is irritation or unrest. Next to *ti* is *re*, $8/9$, whose tone color is stronger, but partakes of unrest because of the psychic effort required to appreciate the element of harmony in the ratio of 8 to 9. Evidently the diatonic color of each note of the scale is determined by the ratio its wave-time bears to the wave-time of the key note. During a melody the key note is subconsciously borne in the memory, and each note that is sung is subconsciously compared with it. A change of key makes a corresponding change in the note of reference and shifts the diatonic colors to the new position of the scale.

[1] Musicians still persist in calling these intervals "half tones," which is as foolish as it would be to call the unit of length a "half meter."

The diatonic color of a note is therefore determined by the interval between it and the key note. It is evident that any interval between successive notes of a melody must in the same way produce in the second note a tone color, which I shall call melodic color. The melodic color of a note may be stronger than its diatonic color and may either reinforce, modify, neutralize, or even reverse the diatonic color. Melodic colors occur in all possible chromatic intervals, and all these intervals are found between notes of the diatonic scale. The following table gives the tone color of each chromatic interval, the words being suggestive rather than exactly descriptive.

Note	Interval	Tone Color
do	12	Boldness, defiance.
ti	11	Suspense, restlessness.
	10	Awe, dread.
la	9	Apprehension.
	8	Pleasure.
so	7	Brilliance.
	6	Strangeness.
fa	5	Depth of feeling.
mi	4	Agreeable mildness.
	3	Sorrow, depression.
re	2	Anger, resentment.
	1	Irritation.
do	0	Confidence, rest.

Melodic color exists not only between the successive notes of a melody but to some degree between any two of its notes. The accented notes form, by themselves, through their diatonic and melodic colors, a skeleton which expresses the stronger characters of the melody. The color of a musical phrase may be so pronounced that its essential character is retained in various positions on the scale. Here are the endless possible combinations in which composers revel, guided by a sense of feeling, often with no clear consciousness of the elements of their art.

A third variety of tone color, which may be called harmonic, arises from the relation of the upper note of a common chord to its ground note. The ground note is already in the subconscious memory in relation to the key note, and the upper note adds to its other colors some of the color of the ground note. The middle note of a major common chord is the upper note of its relative minor, and its harmonic color is that of the ground note either of the minor or of the major weakened.

					Relative Wave-times	
Tonic chord	do	mi	*so*		15: 12: 10	
Its relative minor........la	do	*mi*			6: 5: 4	
Subdominant chord	fa	la	*do*		15: 12: 10	
Its relative minor........re	fa	*la*			6: 5: 4	(nearly)
Dominant chord	so	ti	*re*		15: 12: 10	
Its relative minor........mi	so	*ti*			6: 5: 4	
Dominant seventh ....so	ti	re	*fa*		15: 12: 10: $8\frac{1}{2}$	(nearly)

Each chord has its own chord color, which is totally distinct from its harmonic quality, and is, speaking broadly, like the diatonic color of its ground note. The wave-time ratios are identical in the three major common chords. Their harmonic characters are therefore exactly alike. But there are differences in the ratios to the key note. These ratios are as follows. (See the table on page 146.)

Tonic chord (and key)	$1:1:\frac{4}{5}:\frac{2}{3}$	or	$15:15:12:10$
Subdominant chord	$1:\frac{3}{4}:\frac{3}{5}:\frac{1}{2}$		$20:15:12:10$
Dominant chord	$1:\frac{2}{3}:\frac{8}{15}:\frac{4}{9}$		$22\frac{1}{2}:15:12:10$

The order of simplicity of the ratio to the key note is the order of strength of the chord color.

The elements of music are three, namely,

1. Rhythm, including time and accent,
2. Melody, the succession of notes.
3. Harmony, including tone quality in general.

Of these elements rhythm is the most fundamental and was without doubt the first to be developed. It is still the most important element in popular music. The moving power of a brass band depends on the drum as much as on any other instrument.

Melody, though it comes second in the order of importance and in the order of development, has been the last to be scientifically analyzed. Tone color is the key to its mysteries.

Harmony was practically unknown before the year 1000 A.D., and most of its development has occurred during the last 300 years. Its principles depend upon the mathematical ratios of wave-times, and are well understood.

A fourth element, suggestion, belongs rather to the listener than to the music, for its effects depend upon former experiences of the listener.

Suggestion acts (*a*) by imitation, as when the rippling of water is represented on a piano, or the cry of a child on a violin; (*b*) by natural association, as when lightning is suggested by an imitation of thunder; or (*c*) by individual association, as when some experience of joy or sorrow is recalled on hearing some associated music.

The best and strongest music combines all these elements to produce the desired effects. A clear understanding of the part played by each element in musical composition will lead to a marked improvement in the music produced.